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Original Article

MODELING AND MAPPING OF THE WATER EROSION RISK USING GIS / RUSLE APPROACH IN THE BOUREGREG RIVER WATERSHED

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ABSTRACT

Morocco is among the world's most affected regions by the phenomenon of soil erosion. Thus, issues related to erosion phenomena are perceived both upstream by land degradation, and downstream by the dam siltation affecting the mobilization of water resources, vital for socio-economic development.

It is therefore imperative to evaluate spatially and quantitatively the effects of soil erosion in order to face the phenomenon and to be able to propose development projects and better anti-erosion strategies. The purpose of this study is to evaluate the losses in soils or in sediments generated by soil erosion and mainly sheet erosion and rill erosion. This soil erosion risk prediction will be made by a GIS / RUSLE approach within the Bouregreg river watershed in order to locate potential areas of sediment production and act as a base document for the identification of priority areas. It is also a valuable cartographic material for the planner to design appropriate management planning to counteract the effect of water erosion and its impact on the SMBA dam water retention.

KEYWORDS: Modeling, RUSLE, GIS, Water Erosion, Bouregreg River Watershed, Sidi Mohamed Ben Abdellah Dam & Morocco

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INTRODUCTION

Soil erosion is a widespread phenomenon in the countries around the Mediterranean and it continues to grab considerable proportions of soil. (Paroissien J.B, Darboux F., Couturier A., Devillers B., Mouillot F., Raclot D, 2015).

The Bouregreg river watershed is one of the main rivers in the Moroccan hydrographic network. Its catchment area, elliptical in shape, covers a total area of 395,600 ha. The basin is subject to various natural hazards (climate change, water erosion responsible for soil loss and siltation of the Sidi Mohamed dam, solid transport, etc.) and anthropogenic pressures on natural resources (deforestation, overgrazing, changes in cultural practices, etc.).

Located downstream the Bouregreg river, the SMBA dam is already experiencing a siltation problem affecting both the water retention capacity and its water quality, exclusively intended for the drinking water supply of the coastal area located between Kenitra and Casablanca, where the country's population and industrial and

economic activities are concentrated.

The objective of this case study of the SIG-RUSLE technology application is to quantitatively assess erosion risks at the Bouregreg river watershed. This is a systemic approach based on a multi-criteria method that makes it possible to map the various factors that contribute to the erosion process (lithology, rainfall, topography, vegetation cover, etc.) and to express the soil vulnerability level to erosion. This RUSLE methodology integration with both GIS and remote sensing is expected to provide a useful tool for assessing erosion risk measures and proposing conservation plans at the watershed scale.

STUDY AREA

The Bouregreg river watershed represents the hydrological unit drained by the Bouregregriver and its tributaries. It corresponds to the water collection area bounded by the contour. Within this area, surface water is accumulated and channeled to the common outlet which is the reservoir of the Sidi Mohamed Ben Abdellah dam (S.M.B.A).

With an outline of 536.8 km in length and a drainage area of 3956 km2, the Bouregreg river watershed is limited to the north and the north-east by the Sebou river basin and to the south and the south-east by that of OumEr-Rbieriver. It is located southeast of the city of Rabat and extends to the Middle Atlas chain (Figure 1). This mountain range gives it a diversified relief, and significant hydric potential consisting mainly of runoff or surface water.

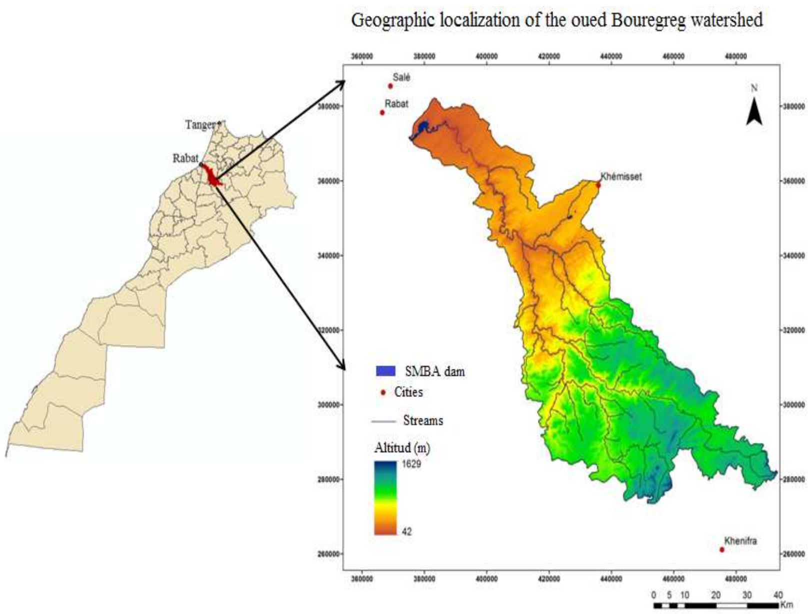

Figure 1: Geographical Location of the Bouregreg River Watershed

Weather stations in the Bouregreg river Basin have good spatial coverage (Figure 2) over long periods of observation (1974-2005).

Administratively, the watershed falls within the territory of the Economic Regions of Rabat SaléZemmourZäaer and MeknèsTafilelt. These regions cover, respectively, 61.5% and 38.5% of the basin area. The distribution by province shows that 93.2% of the territory is concentrated in the provinces of Khémisset and Khénifra.

Hydrologically, the Bouregreg river watershed (delimited between the watersheds of Grou and Beht rivers) is subdivided into five sub-basins on the basis of these five main tributaries: Aguennour river, low and medium

Bouregregrivers, Tabahhart and Ksiksou rivers. 52% of the watershed area is occupied by the last two ones (Figure 2)

The altitudes vary between 60m and 1627m and the highest point is reached at the summit of JbelMzourgane (1627m) south-west of Aguelmous. 60% of the basin's territory consists of altitudinal ranges of less than 1200m and about 40% of the area has altitudes between 800 and 1200 m. The rugged part of the watershed is located mainly in the Middle Atlas.

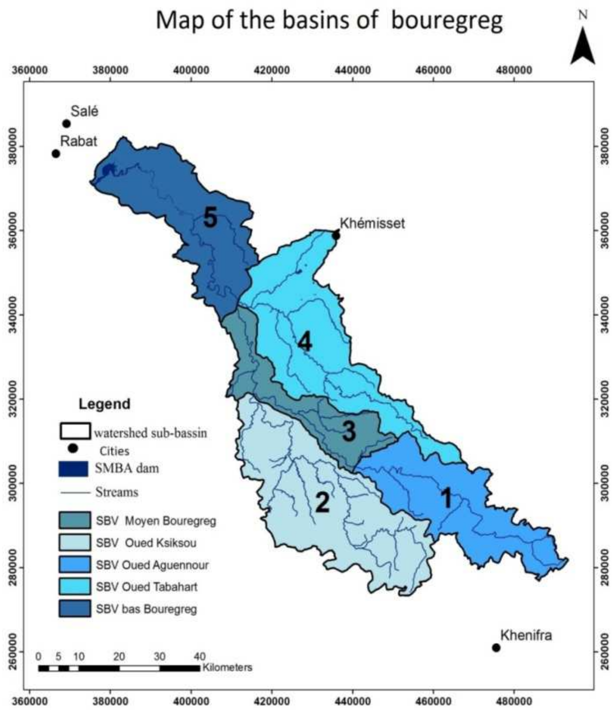

Figure 2: Distribution Map of Sub-Basins (SB) of the Bouregreg River

The topography of the watershed is a mid-mountain area characterized by relatively low slopes. In general, the terrain is more rugged and steep in the central and upstream part of the basin. Areas with a low slope ranging from 0 to 15% which represent 55.7% of the basin territory, against 44.3% for areas with medium to steep slopes.

From the lithological point of view, the watershed is dominated by moderately resistant lithologic formations that include shale, flysch and calcareous crusts (Beaudet, 1969, Ghanem, 1981, D. P. de Khémisset, 1995). This lithological ensemble covers about 79% of the total area of the watershed. Most of the outcrops in the basin are schist and flyschs. The latter concern about 40% of the catchment area and are followed by resistant lithological formations (10%) which include limestones, sandstones, granites, microgranites, and granulites.

The average annual rainfall at the watershed level is generally between 400 mm and 800 mm / year. The bioclimate in the watershed varies from semi-arid to subhumid with cool to hot variants.

MATERIALS AND METHODS

Model Presentation

Our methodological approach of work consists of the integration and the representation of cartographic and descriptive information of the different factors and parameters of the erosion in a geographic information systems platform. The model is presented in the following relationship:

A = R * K * LS * C * P

A: Average annual soil losses expressed in (t/ha/year);

R: Rainfall erosivity factor;

K: Soil erodibility factor;

LS: length and slope gradient factor;

C: vegetation cover factor;

P: conservation practices' factor.

The application, carried out using the RUSLE equation, by mapping the different contributing factors in the process of erosion under GIS and their overlaying results in a quantitative map of the soils erosion hazard. The various model factors are all earth loss ratios related to the influence of each factor so that the product of the set is the total land loss rate of the study area.

In this context, this work aims at modeling the erosion hazard by developing a vulnerability map of the Bouregreg catchment area, taking into account the physico-climatic factors responsible for water erosion. This map will serve as a basic document for the identification of priority areas. It is also a valuable cartographic material for the planner to design and schedule appropriate watershed-scale management planning. (Figure 3)

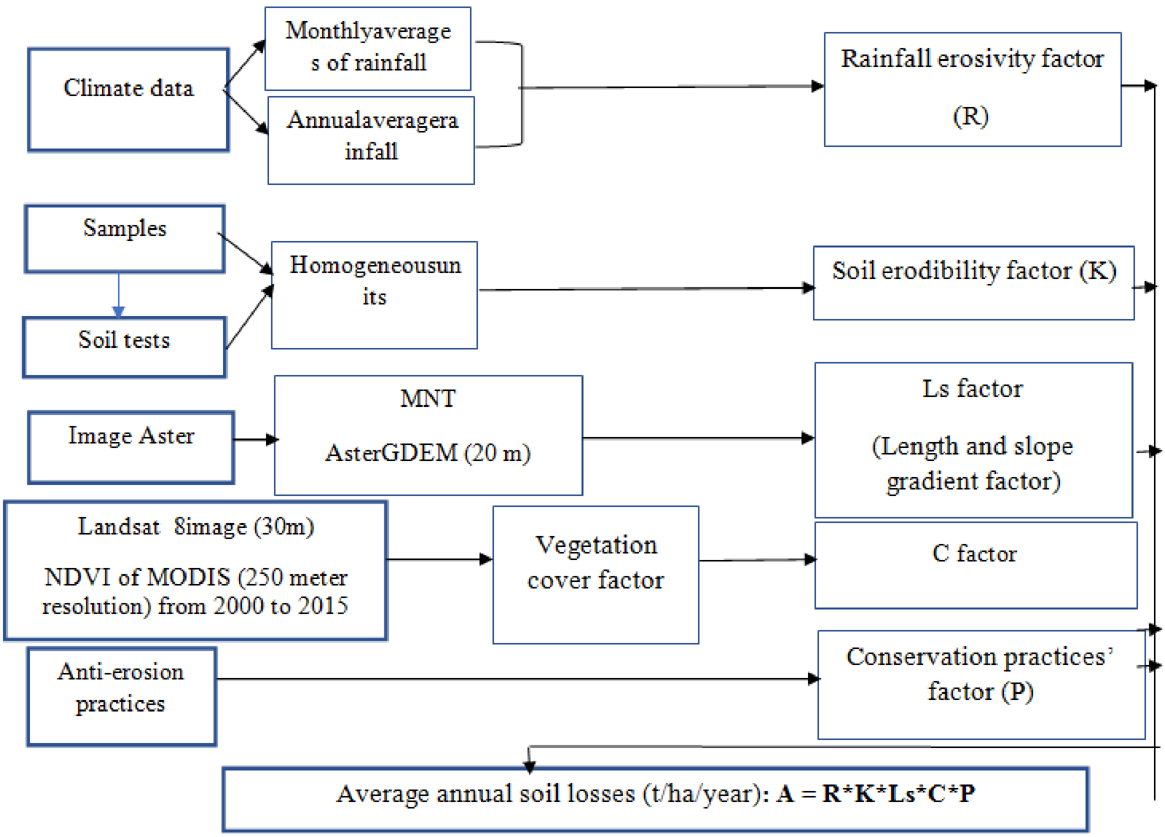

Figure 3: Methodological Flow Chart of the Applied RUSLE Model

RESULTS

Determination and Mapping of RUSLE Parameters

Rain Erosivity Factor (R)

The major part of the catchment area is therefore subject to high rainfall aggressiveness (99.7%). R values exceed 70. Rainfall in the basin is associated with significant erosive power. (figure 4)

Table 1: Importance of Climate Aggression Classes in the Watershed

Class of the Rain Erosivity Factor	Area (ha)	%
< 70	1070	0,3
70 – 80	176 830	44,7
80-90	103276	26,1
90-100	67850	17,2
> 100	46574	11,8
Total	**395600**	**100**

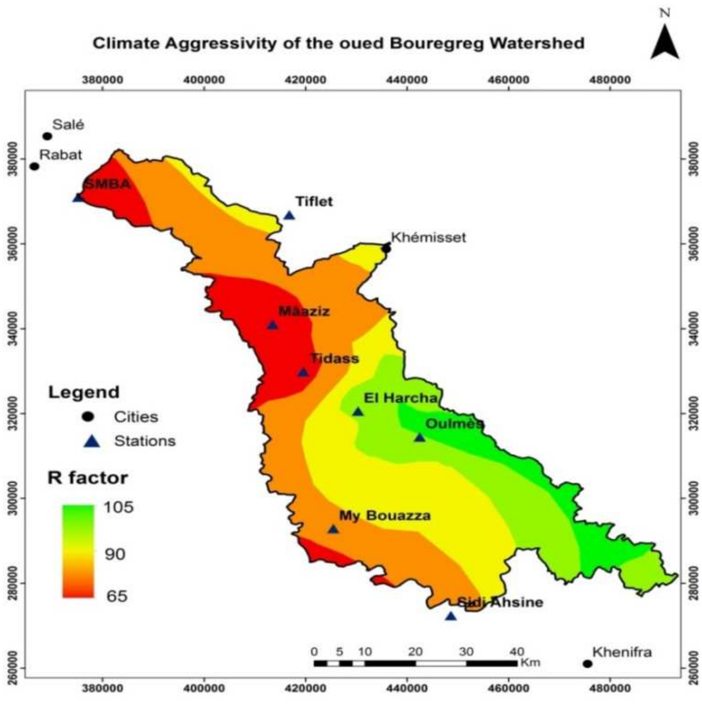

Figure 4: Spatial Distribution of Factor Values (R)

Determination of Soil Erodibility Factor K

Soil erodibility is an indicator of the ease with which soil particles break off. It is a function of the soil structure, its texture, grain size, amount of organic matter and permeability. The watershed is dominated by soils with a high predisposition to erosion (K-factor is between 0.045 and 0.065) and covers an area of approximately 341 000 ha, corresponding to 87% of the total area (Table 2).

Table 2: Erodibility Factor K Classes Distribution in the Bouregreg River Watershed

K Factor Classes	Area (ha)	%
K <0,035	12045	3,04474216
0,035 <K <0,045	38571	9,75
0.045 < K <0.055	158230	39,9974722
0.055 < K < 0.065	171023	43,2312942
K > 0.065	15731	3,97649141
Total	**395600**	**100**

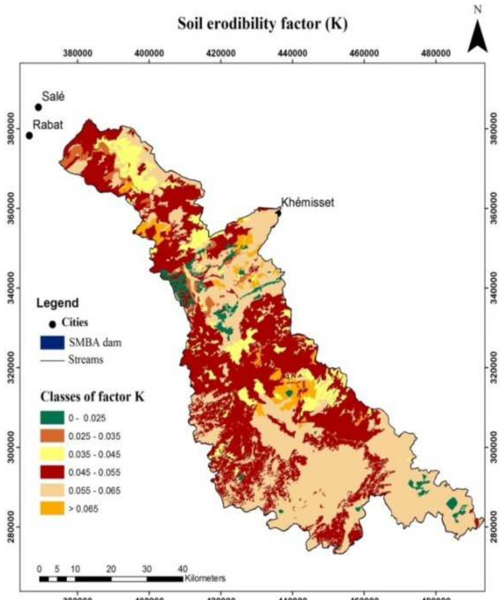

Figure 5: Spatial Distribution of the Factor (K)

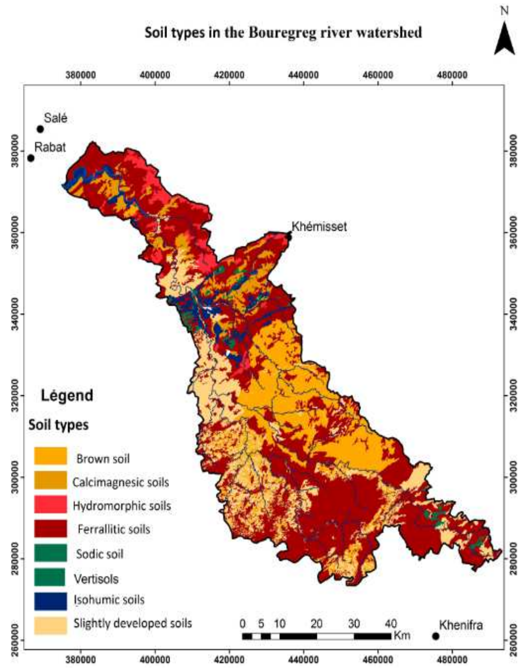

Figure 6: Soil Type in the Bouregreg River Watershed

It should be noted that the higher values correspond to the less erodible soils, while the lower values correspond to the more resilient soils. Soils with silty texture and sandy loam are more erodible. On the other hand, soils with a high proportion of clays have a lower K-value (vertisols, hydromorphic isowet). (Figure 5 et 6)

Determination of Topographic Factor (LS)

The topographic factor influencing erosion has two essential elements: the length of the slope and the incline. The increase in the erosion rate results mainly from the combined effect of its two factors. In principle, the longer the slope; the more runoff accumulates, increases in speed and energy, and erosion increases.

The topographic factor LS is ranked with values ranging from 0.5 to 35.5 with an average for the whole basin equal to 7.40. The spatial distribution map of the LS factor shows that the strongest values logically locate in the more rugged parts of the basin. This is an indication of the importance of topography in the soils' erosive process. (Figure no 7)

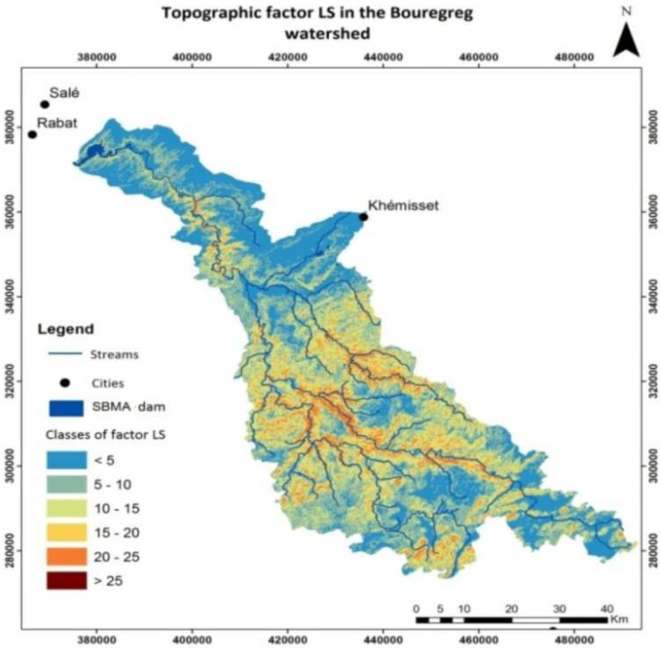

Figure 7: Topographic Factor LS

The importance of the class distribution of this factor is given in Table 3. The watershed is dominated by the LS class below 5 followed by the 5-10 class. Both classes represent about 2/3 of the watershed total area. The highest LS class (> 20) covers about 18% of the basin area, generally coinciding with high altitude and high slope areas and located successively in sub-basin areas 2 and 4.

Table 3: LS Classes' Distribution in the Watershed

LS Factor Classe	Area (ha)	% Area
< 5	171090	43,1
5-10	70180	17,7
10-15	42320	10,7
15-20	41080	10,4
20-25	57140	14,4
> 25	14790	3,7
Total	**395600**	**100**

Vegetation Cover Factor (C)

The recovery rate calculation results, for all watershed occupations, show that more than 78% of the study area has a low quality of cover protection against erosion. Areas with a high to very high recovery rate coincide with the forested areas and represent 22% of the basin's territory and show fairly high protection against erosion. (Figure 8)

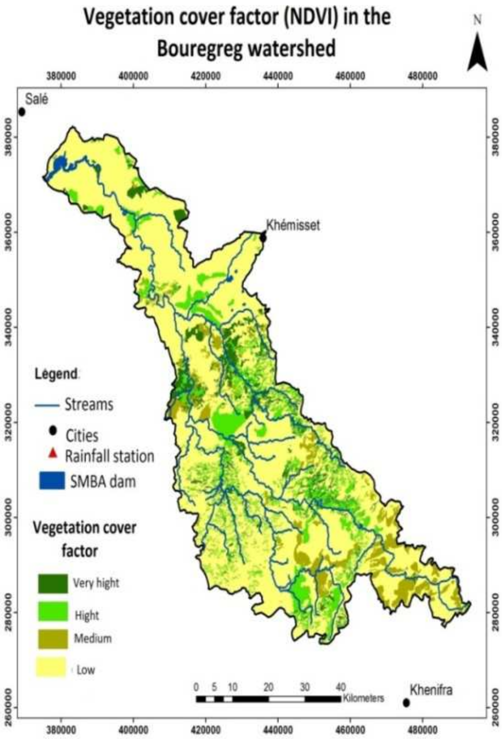

Figure 8: Vegetation Cover Factor in the Bouregreg Watershed (NDVI)

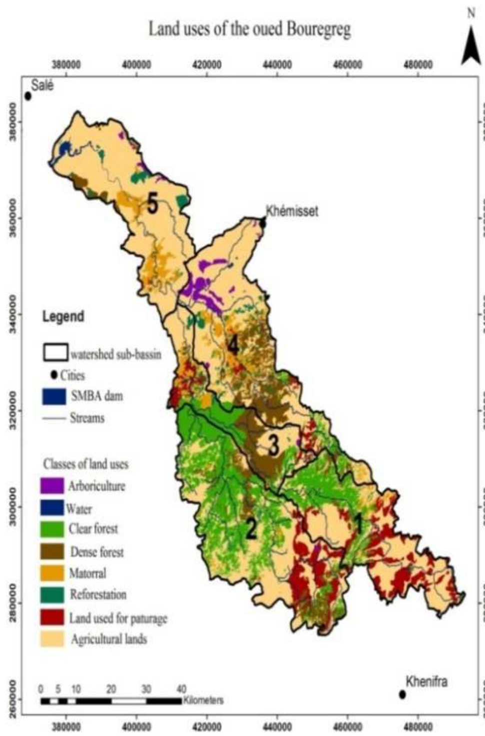

Figure 9: Land uses of the Bouregreg River Basin

Land use in the watershed is characterized by the predominance of agricultural land (57.10%) followed by forests (29.34). Rangelands and Thicket/Scrubland, in turn, represent 11.4% against 2.14% for reforestation. Cultivation sites are located in low slope areas and particularly in the downstream and upstream parts of the watershed. These lands occupy more than half of the watershed total area and are characterized by rainfed crops, particularly cereals. The irrigated part remains narrow and is located in the valleys of the wadis with the permanent flow. (figure 9)

The factor C map shown in Figure 11 shows values between 0 and 0.8.

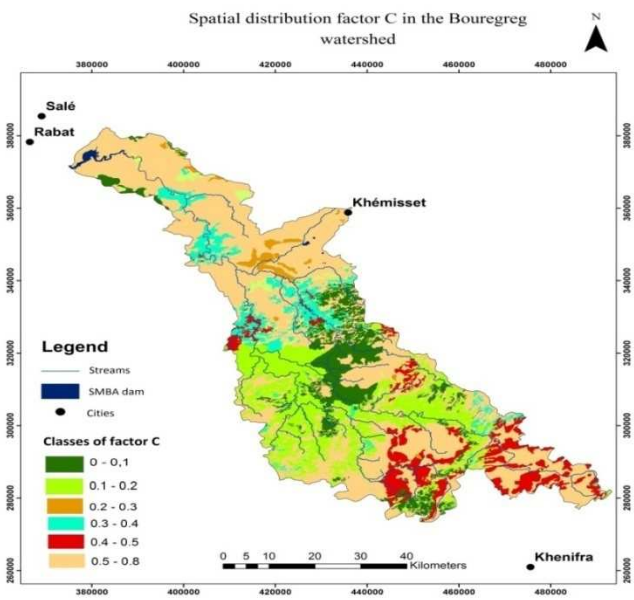

Figure 10: Spatial Distribution Factor C

The vegetation cover protects the soil and ensures the amortization of raindrops and the slowdown of runoff. The factor C map shown in Figure 11 shows values between 0 and 0.8. Values for different land use patterns range from 0 to 0.1 for dense forests; 0.18 (clear forests); 0.6 (Cropland) and 0.45 (rangeland). (Table 4)

Table 4: C Factor Values Assigned for Each Soil Occupation Class

Classes of Land use of the Soil Assigned Values of C	Valeurs de C Attribuées
Dense forest	0,05
Clear forest	0.18
scrub	0,35
Planting area	0,25
Grazing land	0.45
Cropland	0,60

In general, there is a fairly low level of soil protection throughout the basin because most of its area is occupied by cropland. The low protection class (> 0.45) covers more than 60% of the basin area. Land use is a determining factor that has a significant effect on erosion rates. Soil losses on bare or severely degraded lands are probably higher than those on permanently vegetated areas, even on steep slopes.

Cultural Practices Factor (P)

This factor reflects the effects of conservation practices that reduce both the amount and the speed of runoff and hence the importance of erosion.

For cropland, farmers hardly use anti-erosion cultural practices (contour crops, alternating strips or terraces). Crops are mostly cereal crops and plowing parallel to contour lines is almost non-existent. These lands, as well as the rangelands, Scrublands, badlands, and forests, are assigned a value of 1.

Erosion Assessment

The results of the spatial analysis of the erosive hazard indicate that erosion rates vary between 2.14 and 68.2 t / ha / year distributed over the entire study area, with an average of 13.81 t / ha / year, which is relatively high. Erosion in the Bouregreg river watershed, upstream of the Sidi Mohamed ben Abdellah dam is strong since almost 61% of its area is subject to erosion that exceeds the average soil tolerance threshold.

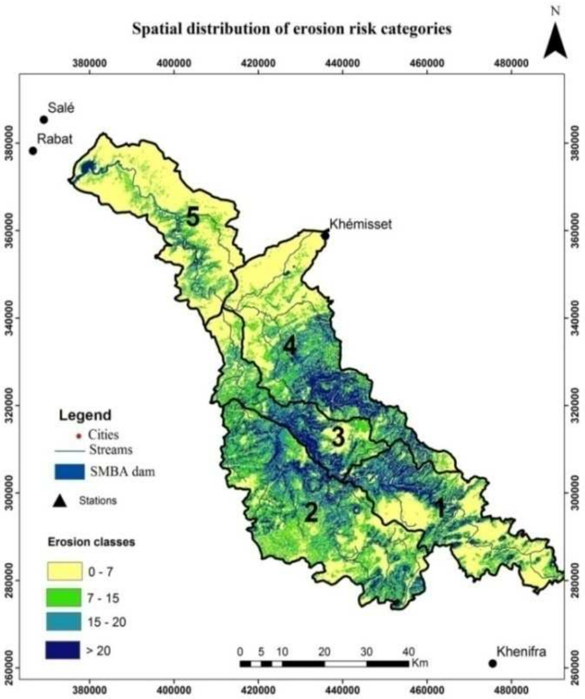

Figure 11: Water Erosion Map in the Bouregreg River Basin

We classified the soil loss map into 4 classes for a better spatial visualization of soil losses, yet the discussion of the results will take into account the following thresholds: low erosion (0-7 t / ha / year), Moderate (07-15 t / ha / year), high (15-20 t / ha / year) and very high (> 20t / ha / year). Table n°5 shows the distribution of erosion classes in the whole basin.

Table 5: Erosion Classes Distribution in the Bouregreg River Watershed

Soil Losses Classes	Area (ha)	%
0-7	153 327	38,66
7-15	114 629	28,90
15-20	71 920	18,14
Sup 20	56 724	14,30
Total	**396 600**	**100**

Table 5 shows that classes 0-7 t / ha / year and 7-15 t / ha-year respectively occupy 39% and 29%. The highest values represent approximately 32% and have been located in steep areas mainly in the sub-basins n° 2 of Ksiksou and n) of Tabbahart.

The results' analysis for the five sub-basins (Table n°6) shows that the Ksiksou sub-basin has the highest value of A (RUSLE) with 18.64 t / ha / year. The actual annual loss for this sub-basin is of 2,063,448 t / year. The Tabahhart sub-basin, meanwhile, has a value of A (RUSLE) = 15.21t / ha / year, with an actual real annual loss of 1.442.668, 5 t / year.

Table 6: Distribution Soil Losses' Classes in the Bouregreg River Watershed

Sub-Basin	Main Tributary	Area en Hectare (ha)	A (RUSLE) (Tonne/ha/Year)	Average Annual Loses (Tonne/Year)
1	Aguennour	70830	13,84	980.287,2
2	Ksikssou	110700	18,64	2.063.448
3	Middle Bouregreg	44040	9,67	425.866,8
4	Tabahhart	94850	15,21	1.442.668,5
5	The lowBouregreg	75180	7,35	552.573
Watershed		***395600***	13,81	5.464.843,5

As a result, the highest quantities of sediments are recorded respectively in sub-basins 2 and 4, which account for more than 64% of the annual yield recorded on all slopes before partially reaching their outlets and then ending at the level of the watershed main outlet. The average value of A (RUSLE) for the whole Bouregreg river watershed is of 13.81 t / ha / year.

Effectively, the results of the flood analysis show that sub-basins 2 and 4 correspond to the highest values of Qmax with, respectively, 514.93 and 447.47 m3 / s. These sub-watersheds come first in presenting potential danger in terms of flood generation. They should be the focal point of any future intervention aiming at limiting probable floods. subbasin No. 1 also has a maximum flow rate to consider because it exceeds 300 m3 / s. (Figure 12)

As a result, areas adjacent to the SMBA dam (subbasin 5) also have high values of potential erosion. These areas are characterized by an average friability rate and altitudes (less than 400 m). Thus the great erosive power of these conterminous areas to the dam is an actual danger involving the siltation of dam retention and compromising its life span.

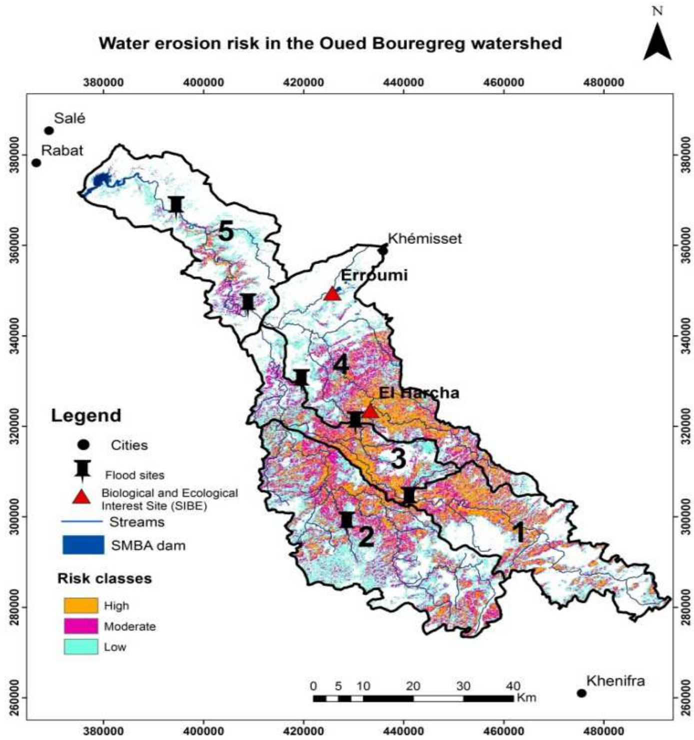

Figure 12: Potential Risk Map for Flood Generation in the Bouregreg River Basin

CONCLUSIONS

The present study has shown a cartographic approach based on the integration of spatial remote sensing tools(GIS) and statistical analysis functionalities linked to the initial state of Bouregreg watershed to study vulnerable areas to erosion and how to protect the watershed.

The spatial analysis results of the erosive hazard indicate that erosion rates vary between 2.14 and 68.2 t / ha / yr distributed over the entire study area, with an average of 13.81 t / ha / year, which is relatively high.

Assessing and mapping the risk of soil erosion is an essential tool for planning the conservation of natural resources in watersheds. This paper aims to spatialize and quantify the actual water erosion in the Bouregregriver watershed using the RUSLE model. The problem of soil erosion approached through the Wischmeier& Smith equation is readily applicable to Geographic Information Systems by compatibility between the USLE and map algebra.

GIS provides a rational way to manage a multitude of spatially referenced data related to various factors of soil degradation, which has allowed us to conclude the main factors that influence water erosion. The application of the RUSLE model allowed us to elaborate on the erosion map which provides synthetic and systematic information on the intensity and spatial distribution of the phenomenon of water erosion. The results obtained, in cartographic format, can provide valuable support to decision-makers and management planners in order to simulate evolution scenarios and subsequently target priority areas that require rehabilitation measures for degraded areas through biological and non-biological fight actions against erosion.

REFERENCES

1. *AdilMoussebbih, Modeling predictors of poverty: the case of common Watershed Bouregreg, REMSES, 2016*
2. *A Guide For predicting Sheet and Rill Erosion on Forest Land, Technical Publication R8-TP6 (Dissmeyer, G.E., Foster, G.R. et USDA, 1984)*
3. *Arnold, J.G., Williams, J.R., Srinivasan, R. and King, K.W. SWAT: Soil and Water Assessment Tool. User's Manual USDA Agriculture Research Service Grassland. Soil and Water Research Laboratory, 808 East Blackland Road Temple, TX 76502, 190 p. (1996).*
4. *Kalman, R. (1967) The Climatic Factor of Erosion in the Sebou Watershed Morocco. Sebou Project, 40 p.*
5. *Paroissien J.B., Darboux F., Couturier A., Devillers B., Mouillot F., Raclot D., Le Bissonnais Y. A method for modeling the effects of climate and land use changes on erosion and sustainability of soils in a Mediterranean watershed (Languedoc, France). Journal of Environmental Management 150 (2015) 57-68.*
6. *Predicting Rainfall Erosion Losses, Agricultural HandBook n° 537 (Wischmeier, W.H. et Smith, .D.1978)*
7. *Predicting Soil érosion by Water : A Guide to Conservation Planning with the Equation (Book number 703)*
8. *GT, Amangabara. "People’s Perception of Soil Erosion and Its Impact in Imo State, Nigeria." IMPACT: International Journal of Research in Applied, Natural and Social Sciences (IMPACT: IJRANSS) ISSN (P) (2018): 2347-4580.*
9. *Paroissien J.B., Darboux F., Couturier A., Devillers B., Mouillot F., Raclot D., Le Bissonnais Y. A method for modeling the effects of climate and land use changes on erosion and sustainability of soils in a Mediterranean watershed (Languedoc, France). Journal of Environmental Management 150 (2015) 57-68.*

10. *Pushpalatha, K., KUMAR, K., RAO, K., & REJANI, R. (2017). Spatial and Temporal Variation of Câ€"Factor and Soil Erosion in a Semi-Arid Watershed: A Case Study in Mahabubnagar District. International Journal of Agricultural Science and Research (IJASR), 7(5), 175-188.*
11. *Roose, E. (1976) Use of the Universal Soil Loss Equation to Predict Erosion in West Africa. In: Soil Erosion: Prediction and Control, SCSA, Special Publication No. 21, 60-74.*
12. *Roose E. Chebbani R. et Bourougaa L. (2000) - Ravinement en Algérie. Typologie, facteur de contrôle, quantification et réhabilitation. Sécheresse. Vol 11, Numéro pp. 317-326.*
13. *Roose E. (Ed.), Soil and Water Conservation Society, Ankeny (1988) 129-139. 23. ESRI, ArcGIS Desktop (2014) En ligne http:// help.arcgis.com/fr/arcgisdesktop/10.0/help*
14. *Wischmeier W.H., Johnson C.B, Cross BV. A soil erodibilitynomograph for farmaland and construction sites. J Soil Water Conserv 1971; 265: 189-93.*
15. *Wischmeier W.H. and Smith D.D. (1978) Prediction Rainfall Erosion Losses, a Guide to Conservation Planning Science.*
16. *Wischmeier W.H., Smith D.D. A universal soil loss estimating equation to guide conservation farm planning. 7th International Congress of soil sciences, Madison (Wisconsin), I, 1960.*
17. *Wischmeier, W.H. 1976. Use and misuse of the Universal Soil Loss equation. J. Soil Water Conservation. 3 1: 5-9.*
18. *Wischmeier, W.H., and D.D. Smith. 1978. Predicting rainfall erosion losses - a guide to conservation planning. The USDA Agriculture Handbook No. 537.*
19. *High Commission for Water, Forest and Fight against Desertification HCEFLCD (1996) National Watershed ManagementPlan (PNABV).*